HEMP HURD FLOUR AS AN ALTERNATIVE LOW COST FILLER IN WOOD PLASTIC COMPOSITES

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ABSTRACT

Hemp hurd, also commonly referred to as hemp shives, is a low cost byproduct from the decortication process of hemp, retailing for less than 0.2 $/kg. In the context of establishing a hemp agri-fibre operation, value adding to this underutilized waste stream is crucial to improve the overall economics of the operation. In this research the use of hemp hurd as an alternative to wood flour for the production of wood plastic composites is investigated. Hemp hurd filled Polypropylene composites were produced via compounding in a co-rotating twin screw extruder. Taguchi design of experiment methodology in combination with Analysis of Means (ANOM) was used to gain an understanding of the influence of the different processing parameters. Parameters investigated were screw-configuration, temperature profile and fibre loading. Best results were obtained with a relatively gentle mixing zone at a temperature of 200 ºC and 40%wt. and 20%wt. of fibre loading for highest stiffness and highest strength respectively.

KEYWORDS

Wood plastic composites, Compounding, Natural fibres.

INTRODUCTION

Hemp hurd is an underutilised by-product from the decortication process of hemp. Whilst hemp fibres are highly thought after, both for textile as well as for composite applications, hemp hurd is rarely used in technical applications and typically finds its way into animal bedding. Value adding to the hemp hurd is crucial for any hemp agri-fibre operation as only 20-30% of the hemp stem is made up the bast fibres.

The use of hemp hurd as a filler in polymer matrix composites is not entirely new and previous research has shown that properties comparable to the ones obtained using wood flour as a filler (Cigasova et al., n.d.; Khan et al., 2015; Kidalova et al., 2015; Stevulova et al., 2015) can be achieved. As shown in Table 1, the chemical composition of hemp hurd is comparable to wood four. Hemp hurd has a slightly higher ash and cellulose content and a lower hemicellulose content. It is worth noting that whilst the chemical composition of hemp hurd and wood is similar, the microstructure of hemp hurd is very different to the one of wood flour. Therefore a detailed investigation of both chemical surface composition as well as microstructure would be required to relate any composite properties back to the chemical composition and microstructure.

Table 1:Comparison of chemical composition of hemp hurd and wood flour

Components	Hemp hurd (Gandolfi et al., 2013)	Wood four (Xanthos, 2010; Baldock & Smernik, 2002; Poletto et al., 2012)
Ash	2-4	0.4-0.5
Lignin	16-23	21-34
Cellulose	39-49	37-47
Hemicellulose	16-23	19-30

Whilst previous research has already investigated physical and mechanical properties of hemp hurd composites, this research aims to investigate the effect on processing parameters on the final composite properties. The results from this research can be used to optimise the compounding process and will provide future direction to compounding/extrusion research.

MATERIALS

Hemp hurd was sourced from Ecofibre Industries and originates from industrial hemp gown in northern New South Wales (Australia). The hemp hurd was processed into a powder using an air-jet mill (Aximill). A fine powder was produced with a wide particle/fibre size distribution ranging from 10 µm to 500 µm. There was deliberately no use of sifts or cyclone separation to increase the yield. As shown in
Figure 1 the aspect ratio is relatively low and varies from 2-20 for the majority of fibres and particles.

For the study presented here Polypropylene from Lyondellbasell, Moplen HP442M, with a melt flow rate of 8.5g/10 min was used. Maleic-Anyhidride-Polypropylene, Grade Licocene PP MA 6452, from Clariant was used as the compatibiliser. PP MA 6452 was added at 3% per weight relative to the proportion of matrix material used. Details of all materials used in this study are summarised in Table 2.

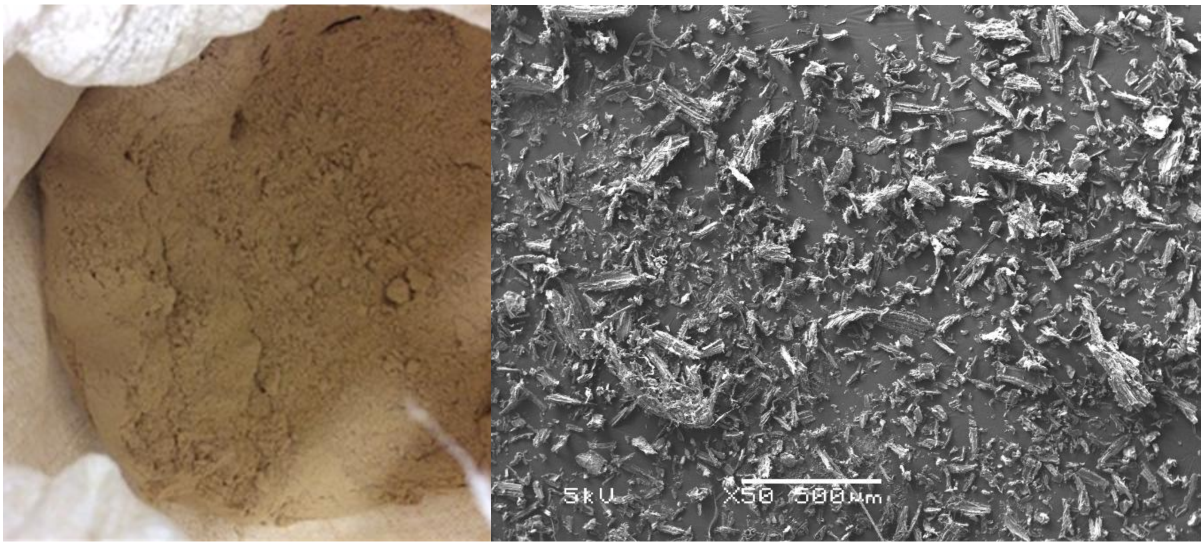

Figure 1: Hemp hurd powder after air jet milling (left) and high resolution scanning electron image of the hemp hurd powder (right)

Table 2:Martials used in the compound formulation

Category	Material	Resources	Description
Fibre	Hemp hurd	Ecofibre Industries Operations Pty, Australia	Undergo second cyclone which is in finely powdered form
Matrix	Polypropylene	Lyondellbasell, Australia	Grade Moplen HP442M, pellet form, a melt flow rate of 8.5g/10 min
Coupling agent	Maleic anyhidride Polypropylene (MAPP)	Clariant Produkte, Deutschland	Grade Licocene PP MA 6452

EQUIPMENT

Compounding was carried out on a parallel twin-screw extruder, PRISM Eurolab XL, with a barrel diameter=16m and a L/D ratio of 40:1. The compound was extruded through a slit die with a width of 100 mm and a height 1.98 mm. The slid die was feed with a melt pump mounted to the end of the barrel. A main objective of the research was to investigate the effect of screw configuration on resulting composite properties. Three screw configurations where tested, ranging from soft to aggressive mixing intensity. The severity of the mixing was controlled via the arrangement of the kneading blocks in the second mixing zone (see Figure 2). Table 3 shows the configuration of the second mixing zone which was used to achieve the three levels of mixing intensity. Fibre and polymer were feed separately. All materials were feed at the start of the barrel but with two separate volumetric feeders. The volumetric feeders were calibrated beforehand to allow precise metering of the fibre/matrix fraction. In order to investigate the effect of processing temperature the barrel temperature was held constant across the entire length of the barrel. The die and melt pump temperature was 190 °C for all combinations tested.

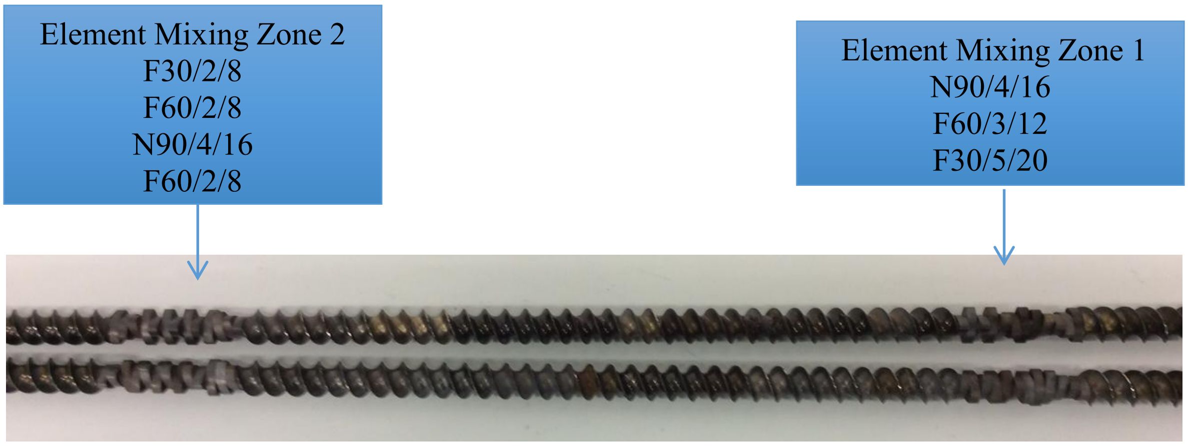

Figure 2: Screw configuration used in the experiments. Only mixing zone 2 was altered to adjust mixing severity

Table 3:Configuration of second mixing zone

Screw configuration	Mixing zone 1	Mixing Zone 2	Notes
1. Aggressive	N90/4/16	F30/2/8	• Reverse elements • Same as Mild configuration with the exception of the reverse elements • Mixing zone 1 identical for all combinations
		F60/2/8	
	F60/3/12	N90/4/16	
	F30/5/20	R60/2/8	
		R30/2/8	
2. Mild	N90/4/16	F30/2/8	• No reverse elements • Same as Mild configuration with the exception of the reverse elements • Mixing zone 1 identical for all combinations
		F60/2/8	
	F60/3/12	N90/4/16	
	F30/5/20	F60/2/8	
		F30/2/8	
3. Soft	N90/4/16	NONE	• No mixing zone 2 • Mixing zone 1 identical for all combinations
	F60/3/12		
	F30/5/20		

F=Forward rotation, N= Neutral, R=Reverse rotation

METHODLOLOGY

Design of experiment (DOE) was used following the fractional factorial design approach by Taguchi. The test matrix consisted of three factors (screw design, temperature and fibre loading) at three levels (see Table 4). Via the fractional design approach by Taguchi the full factorial combination 27 was reduced to 9. Table 5 shows the test matrix with the reduced number of combinations tested as part of this research.

Table 4:Factors and levels used in the design of experiments

	Level		
Factors	1	2	3
Screw design	Soft	Mild	Aggressive
Temperature	190	200	210
Fibre loading (%wt.)	20	30	40

Table 5:Factorial design combinations investigated as part of this research

Trial number	Screw configuration	Temperature (°C)	Fibre loading (%)
1	Soft	190	20
2	Soft	200	30
3	Soft	210	40
4	Mild	200	20
5	Mild	210	30
6	Mild	190	40
7	Aggressive	210	20
8	Aggressive	190	30
9	Aggressive	200	40

RESULTS & DISCUSSION

Tensile test coupons according to ASTM 638-2 type IV were cut from the extruded strips with a water jet cutter. Samples were tested with an INSTRON 5582 universal testing machine equipped with a 1kN load cell and pneumatic grips. An INSTRON optical video extensometer was used to measure the strain. The gauge length was 25mm and a cross head speed of 5 mm/min. Six samples were tested for each combination.

The test results are shown in Table 6 and the ANOM analysis results are shown in Figure 3 and
Figure 4. As expected, the addition of the hemp hurd filler lead to a significant increase in stiffness. For Run 6 the recorded average tensile modulus was 2.02 MPa which is a 83% increase in modulus compared to the virgin PP. The increase in modulus comes at the cost of a reduction in elongation to break. The elongation to break for the filled specimens ranges from a low 1.34 % to a more acceptable 4.03 %. It is somewhat surprising that a modest increase in tensile strength was also recorded for all but two combinations tested. The maximum average tensile strength recorded was for Run 1 where an average tensile strength of 28.98 MPa was measured. This corresponds to a 16% increase compared to the virgin PP material.

The ANOM analysis provides some interesting insights into the effects of the three processing parameters, screw configuration, fiber loading and temperature. The barrel temperature appears to have a relatively small effect on both modulus and tensile strength of the extruded specimens. As shown in Figure 3 and
Figure 4, the best tensile strength and modulus are obtained at 200 °C. It is expected that temperatures above 200 °C degrade the filler and hence result in a reduction of the final properties. A likely explanation for the lower results at 190 °C could be the higher viscosity of the polymer resulting in less mixing and/or more shear during mixing. The findings in relation to the mixing zone configuration are interesting as they suggest that a relatively mild mixing is sufficient during the compounding process. Both tensile strength and modulus show higher values for a gentle mixing zone configuration. A possible explanation for this trend is that excessive mixing might leads to fibre attrition and hence reduce the reinforcement effect of the fibres. The increase in modulus with increasing fibre loading was to be expected. As shown in Figure 3 there is a noticeable increase in tensile modulus as the fibre loading is increased. As already mentioned the increase in modulus comes at the cost of elongation to break with the results following the same trend as the tensile strength. A sharp drop in tensile strength is observed when the fibre loading is increased (see
Figure 4). This reduction in tensile strength is most pronounced when the fibre loading is increased from 20%wt. to 30%wt. A further increase in fibre loading does not significantly drop the tensile strength.

Table 6: Tensile test results

Run	Screw design	Fibre loading (% wt.)	Temperature (°C)	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation at break (%)
1	Soft	20	190	28.982	1.601	4.03
2	Soft	30	200	24.970	1.870	2.21
3	Soft	40	210	20.646	1,871	1.48
4	Mild	20	200	27.179	1.494	2.74
5	Mild	30	210	25.966	1.630	2.28
6	Mild	40	190	27.146	2.023	1.42
7	Aggressive	20	210	28.301	1.510	3.3
8	Aggressive	30	190	22.478	1.428	1.7
9	Aggressive	40	200	25.938	1.960	1.34
R	Reference pure PP			24.89	1.105	>50

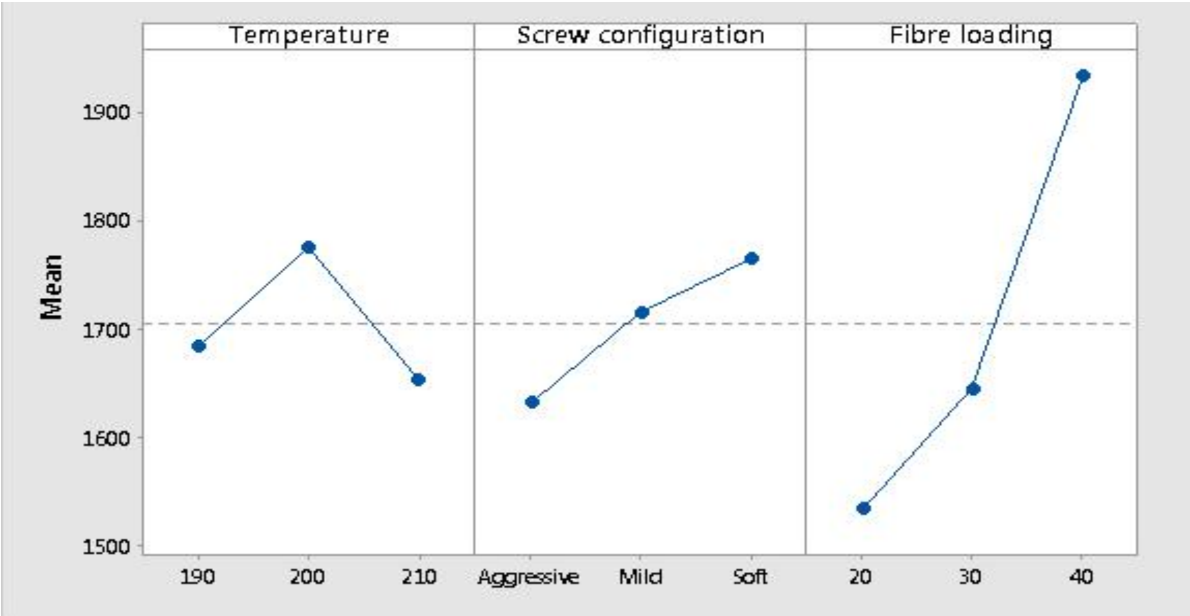

Figure 3: Main effect plot for tensile modulus in MPa

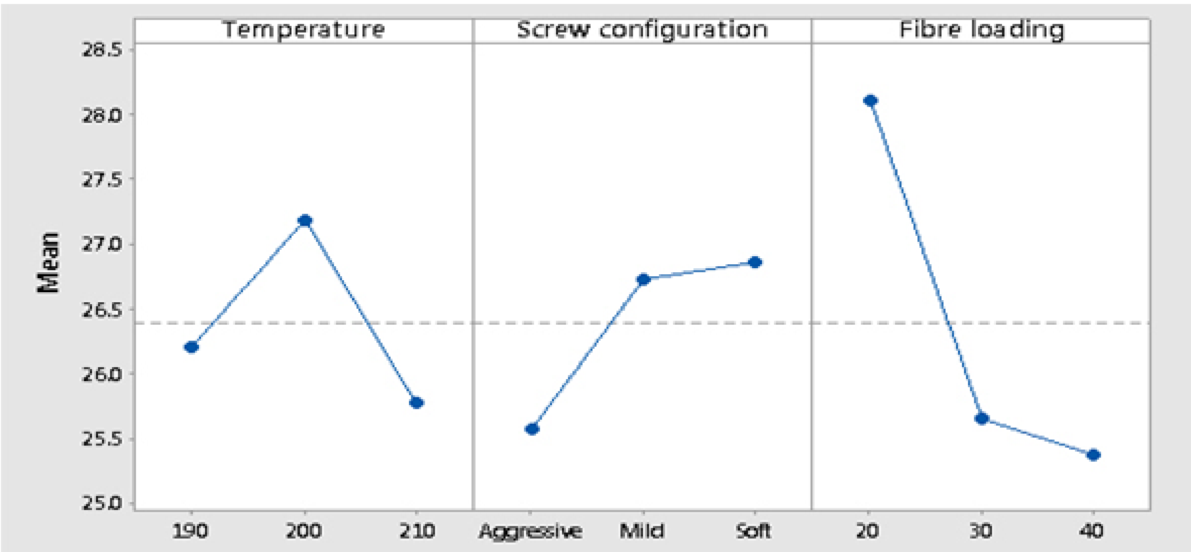

Figure 4: Main effect plot for ultimate tensile stress in MPa

CONCLUSION

The results presented in this paper show that finely ground hemp hurd flour can be used as a filler in poloyolefine matrix composites. By using an efficient processing method, such as the air-jet milling trialed in this research, the cost of the filler can be kept low compared to other filler alternatives. With a cost of 0.2-0.3 $/kg the filler is 3-5 times cheaper than most other filler alternatives such as natural or glass fibres. However, the properties obtained are not as good as what is typically reported for short natural or glass fibre composites using the same matrix material. The research has shown that a significant increase in stiffness of up to 83% can be obtained. The gains in strength are however modest (max. 16%) and the elongation to break is drastically reduced compared to the virgin material. The ANOM analysis has shown that all three parameters investigated have a distinct effect on the final composite properties. The results suggest that a processing temperature of 200 °C and a soft mixing zone configuration is the most promising parameter configuration irrespective of one aiming to optimise strength or stiffness. The trend for stiffness and strength in relation to fibre loading are opposed and whilst an increase in fibre loading increases the stiffness at the same time strength is significantly reduced. From an economical aspect a high fibre loading is desirable as the overall compound cost is reduced by the addition of the filler. It is expected that under the right processing conditions a compound with a tensile strength of 28 MPa and a modulus of 2 GPa can be obtained. Due to the low cost of the hemp hurd it is also expected that the cost of the final compound can be reduced by 30-40%. These properties make the produced material a low cost alternative for wood replacement in non-structures building and construction applications. To further investigate the suitability of these materials for applications in building and constitution industry the long-term behavior of these materials needs to be carefully investigated, paying particular attention to creep and environmental degradation behaviour.

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